Radiotherapy-induced supra-aortic trunk disease: Early and long-term results of surgical and endovascular reconstruction

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Purpose: **Few articles have dealt specifically with management of radiotherapy-induced supra-aortic trunk disease. We investigated the results of surgical and endovascular treatment of these lesions, and present our findings in a large series of patients.**

Methods: **The study was conducted at 11 centers. Over 10 years 64 patients with radiotherapy-induced supra-aortic trunk disease underwent surgical or endovascular treatment. Data were collected retrospectively in a consecutive cohort of patients, and were analyzed with the Kaplan-Meier method.**

Results: **Mean patient age was 64.4 years. The indications for radiotherapy included breast cancer (30%), head and neck malignancies (50%), and lymphomas (19%). The mean interval between irradiation and arterial revascularization was 15.2 years. Thirteen of the 64 patients (20%) had asymptomatic disease, and 51 patients (80%) had symptomatic disease. Ninety-two stenotic or occlusive lesions were observed, which involved the common carotid artery (n = 62), the subclavian artery (n = 26), or the innominate artery (n = 4). Twenty-three patients (36%) had multiple supra-aortic trunk lesions, but only 8 patients underwent reconstruction of multiple supra-aortic trunks. Five patients (8%) underwent sternotomy for revascularization from the ascending aorta. Forty-seven patients required revascularization of a common carotid artery; procedures included bypass grafting (n = 30), angioplasty with stent placement (n = 13), carotid-carotid transposition (n = 2), and endarterectomy (n = 2). Fifteen patients underwent restoration of a subclavian artery. One patient died on postoperative day 5, of stroke after early occlusion of an intercarotid crossover bypass graft. Mean follow-up was 37 months (range, 2-120 months). Ten late deaths occurred during follow-up. The probability of survival at 4 years was 78.1% ± 8.6%. During follow-up, 6 patients had stroke, 4 bypass occlusions occurred and 3 stenoses occurred in the revascularized arteries. At 4 years the probability of freedom from stroke was 85% ± 8.8%. At 4 years the primary patency rate was 79.3% ± 8.5% and the secondary patency rate was 87.9% ± 7.2%.**

Conclusions: **In light of the context, the results of arterial revascularization to treat radiation-induced arterial lesions of the supra-aortic trunk are satisfactory. (J Vasc Surg 2004;40:254-61.)**

Like other arterial territories, the supra-aortic trunk can be injured by therapeutic irradiation. Whether radiotherapy directly induces atheroma or merely accelerates its formation on a predisposed terrain has yet to be determined.[1-3] Correction of vascular risk factors (smoking, arterial hypertension, diabetes) is imperative after radiotherapy. Duplex ultrasound scanning is valuable for surveillance of patients after radiotherapy.[4,5]

Stenotic and occlusive disease accounts for most post-irradiation supra-aortic trunk arterial lesions, although aneurysmal disease,[6] arterial rupture,[7] and fistulas between the innominate artery and the trachea[8,9] have also been reported.

The incidence of radiation-induced arterial disease is difficult to determine, because it varies greatly as a function of anatomic location. For example, subclavian artery involvement is frequent after radiotherapy for breast cancer, and has been the subject of numerous publications.[10-17] In contrast, involvement of the innominate artery is exceptional.[18] Lesions of the intrathoracic segment of the common carotid arteries have rarely been described,[19,20] and appear even less common than involvement of the coronary arteries.[21,22] In contrast, lesions of the cervical segment of the common carotid arteries have been reported more often, generally in series dealing essentially with carotid bifurcation disease.[23-26] Whereas the literature contains numerous publications on radiation-induced disease of the carotid arteries[27-29] or aortoiliac arteries,[30,31] no studies have dealt specifically with radiation-induced disease of the three supra-aortic trunks.

To investigate the results of treatment of radiation-induced arterial disease of the supra-aortic trunk, we retrospectively reviewed all cases treated in our department since 1993. A survey of members of the University Association for Research in Vascular Surgery (AURC) was also conducted to collect as many cases as possible.

METHODS

Review of a list of all patients who underwent arterial revascularization of the supra-aortic trunk between 1993 and 2002 in our Department of Vascular Surgery enabled identification of six patients who had received radiotherapy

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Competition of interest: none.

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Table I. Radiation-induced supraaortic trunk disease: personal series of 6 cases

Patient	*Age (y)*	*Sex*	*Cancer*	*Interval between radiotherapy and surgery (y)*	*Lesion site*	*Symptoms*	*Procedure*	*Follow-up (mo)*
1	45	M	Larynx	6	Right and left common carotid arteries	Regressive right-sided hemiplegia	Aortobicarotid bypass (sternotomy)	55
2	65	F	Right breast	19	Right subclavian artery	Right upper extremity ischemia	Right carotid-humeral venous bypass	120
3	70	F	Right breast Left breast	16 6	Right common carotid artery and left subclavian artery	Amaurosis of right eye	Stenting of right common carotid artery	84
4	69	M	Larynx	10	Left common carotid artery	Transient ischemic attack with right hand deficit	Carotid vein graft	72
5	56	M	Lymphoma	11	Left common carotid artery	Amaurosis of left eye	Carotid vein graft	60
6	77	F	Left breast	15	Left subclavian artery and left common carotid artery	Left upper extremity ischemia and vertebrobasilar insufficency	Carotid subclavian bypass and stenting of left common carotid artery	18

Table II. Number of patients per center

Center	*No. of patients (N = 64)*
Angers	5
Bordeaux	2
Caen	4
Lille	3
Lyon	7
Marseille	5
Nice	6
Paris (Pitié-Salpêtrière Hospital)	23
Paris (Beaujon Hospital)	5
Rome	3
Rouen	1

Table III. Risk factors and comorbidity for 64 patients

	No.	*%*
Smoking	46	72
Arterial hypertension	34	53
Coronary artery disease	14	22
Hypercholesterolemia	13	20
Diabetes	9	14
History of stroke	5	8

for a cancer. All demographic and clinical data were collected via review of hospital records, follow-up visit reports, and telephone contacts. These six cases are listed in Table I.

A survey of members of AURC was also conducted to collect all cases of radiotherapy-induced supra-aortic trunk disease that they had observed since 1994. Ten centers participated in this survey. Data for each patient were recorded on a standardized form with 56 variables. This survey identified an additional 58 patients with radiation-induced arterial disease, all of whom underwent revascularization of the supra-aortic trunk between 1994 and 2002. The number of patients per center is shown in Table II.

Data for 64 patients were collected, the 6 patients in our series and the 58 patients from AURC. Preoperative, perioperative, and postoperative data were recorded and analyzed with database software (Microsoft Excel 2000). Patency, survival rates, and survival free from stroke were calculated with standard life table analysis with the Kaplan-Meier method. Statistical analysis was performed with the Fischer exact test. Statistical significance was accepted at $P < .05$.

RESULTS

The mean age of the 33 men and 31 women was 64.4 years (range, 41-90 years). Antecedents and vascular risk factors are given in Table III. The indications for radiotherapy included breast cancer (n = 19, 30%), head and neck malignancies (n = 32, 50%), and lymphomas (n = 12, 19%; Table IV). The mean interval between irradiation and arterial revascularization was 15.2 years (range, 1-41 years). In all patients cancer was considered cured when arterial reconstruction was performed. Specific information concerning the radiotherapy protocol was available for only 21 patients. The long interval between irradiation and arterial revascularization explains that the radiotherapy protocol was not available for all patients. The mean therapeutic irradiation dose for these 21 patients was 55 Gy (range, 40-70 Gy). Cervical carcinologic surgery (laryngectomy, nodal dissection) was performed in addition to radiotherapy in 17 patients. Three patients had a permanent tracheostomy.

Thirteen of the 64 patients (20%) had asymptomatic disease; in this group the indication for surgery was tight

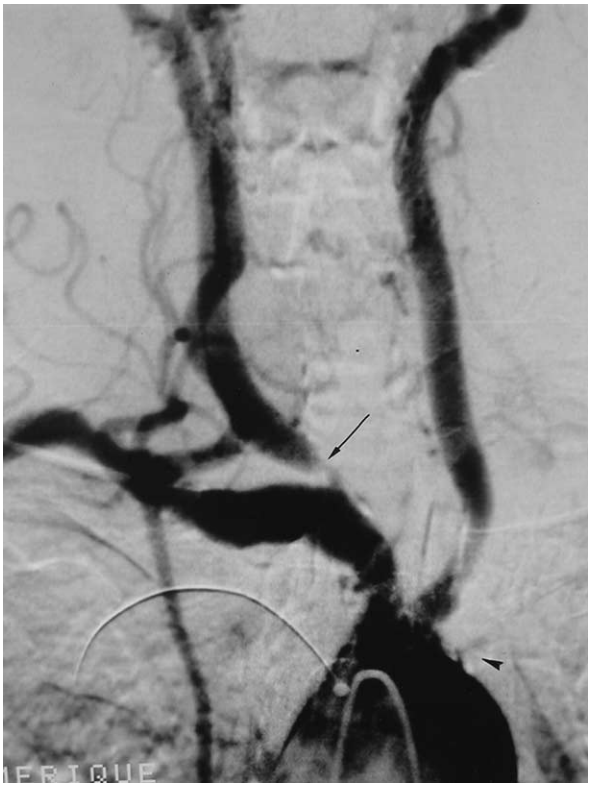

Fig 1. Patient 3. Arteriogram reveals stenosis at the origin of the right common carotid artery *(arrow)* and occlusion of the left subclavian artery *(arrowhead)* in a patient who underwent radiotherapy to treat cancer of the right breast 16 years previously and cancer of the left breast 6 years previously.

Fig 2. Patient 4. Arteriogram shows a long, irregular stenosis of the middle third of the left common carotid artery *(arrow)* in a patient who had undergone radiotherapy 10 years earlier to treat cancer of the larynx.

stenosis of the common carotid artery. The remaining 51 patients (80%) all had symptomatic disease, including transient ischemic attack (n = 26) or minor stroke (n = 37), transient monocular blindness (n = 18), upper extremity ischemia (n = 15), and vertebrobasilar insufficiency (n = 10).

Morphologic workup of the supra-aortic trunk lesions was performed with arteriography in 56 patients, magnetic resonance angiography in 6 patients, and computed tomography angiography in 2 patients. Ninety-two stenotic or occlusive lesions were observed, (Figs 1 and 2) which involved the common carotid artery (n = 62), the subclavian artery (n = 26), or the innominate artery (n = 4). Forty-one of the 64 patients (64%) had involvement of a single supra-aortic trunk (28 isolated common carotid artery lesions, 13 isolated subclavian artery lesions). Twenty-three patients (36%) had multiple supra-aortic trunk lesions. Fifteen of these 23 patients underwent vascular reconstruction of only one arterial trunk, and only 8 patients underwent reconstruction of multiple supra-aortic trunks. In the 19 patients who received therapy for breast cancer, we found 20 lesions of the subclavian artery, 4 lesions of the common carotid artery, and 2 lesions of the innominate artery. In the 32 patients who received therapy for head and neck malignancy, we found 41 lesions of the common carotid artery, 3 lesions of the subclavian artery, and 1 lesion of the innominate artery. Most patients who underwent radiotherapy for breast cancer had lesions of the subclavian artery, and most patients who underwent radiotherapy for head and neck malignancy had lesions of the common carotid artery.

A wide range of arterial reconstruction procedures (n = 14) were performed in the 64 patients (Table V). Five patients (8%) underwent sternotomy for revascularization from the ascending aorta. This approach enabled reconstruction of a single common carotid artery (aortocarotid bypass) in 1 patient and multiple reconstructions of several arterial trunks from the ascending aorta in 4 other patients.

Forty-seven patients required revascularization of a common carotid artery; procedures included bypass grafting (n = 30), angioplasty with stent placement (n = 13), carotid-carotid transposition (n = 2), and endarterectomy (n = 2; Table V). The 30 bypass procedures were performed with carotid vein grafts in 6 cases, polytetrafluoroethylene (PTFE) grafts in 13 cases, carotid-subclavian bypass in 7 cases (5 PTFE, 2 saphenous vein), and intercarotid PTFE crossover bypass in 4 cases. Distal anastomosis of these 30 bypasses was to the common carotid artery, up-

Table IV. Carcinologic antecedents and indications for radiotherapy in 64 patients

	No.	*%*
Breast cancer	19	30
Laryngeal cancer	16	25
Hodgkin disease	7	11
Non-Hodgkin lymphoma	5	8
Tonsillar carcinoma	6	9
Cancer of tongue	5	8
Thyroid cancer	3	5
Cancer of cavum	1	2
Esophageal cancer	1	2
Parotid cancer	1	2

stream of the carotid bifurcation in 5 procedures (17%), and to the internal carotid artery in 25 procedures (83%). Endarterectomy of the carotid bifurcation was associated with reconstruction of the common carotid artery in 4 patients.

Fifteen patients underwent restoration of a subclavian artery, 4 with a PTFE subclavian-carotid bypass, 4 with a carotid-axillary artery bypass (2 PTFE, 2 saphenous vein), 4 with a carotid-humeral artery bypass (3 saphenous vein, 1 PTFE), 1 with a subclavian-humeral artery venous bypass, 1 with venous bypass between the innominate artery and the right axillary artery, and 1 with a Dacron graft bypass between the common femoral artery and the subclavian artery (femoral-subclavian-carotid sequential bypass). No endoluminal angioplasty of the subclavian artery was performed in this series (Table V).

During the immediate postoperative period 1 patient died on postoperative day 5, of stroke after early occlusion of an intercarotid crossover bypass graft. The postoperative course was uneventful in 54 patients. Ten nonlethal complications were observed, including myocardial ischemia (n = 3); revascularization syndrome with cerebral hemorrhage (n = 2), which resolved with complete neurologic recovery after 6 weeks and 3 months, respectively; transient ischemic attack (n = 1), which resolved completely in 2 hours; regressive paralysis of the recurrent nerve (n = 2); paralysis of cranial nerves IX and XII (n = 1); and gastrointestinal hemorrhage (n = 1). There were three postoperative strokes (4.7%).

Follow-up examination was performed at 6-month intervals for 12 months after each operation, and yearly thereafter. Patency assessment included clinical evaluation and duplex scanning. Mean follow-up was 37 months (range, 2-120 months). Five patients were lost to follow-up. Ten late deaths occurred during follow-up. The causes of late deaths included peritoneal carcinosis at 10 months (n = 1), pulmonary embolism at 1 year (n = 1), pleural mesothelioma at 1 year (n = 1), recurrence of laryngeal cancer at 18 months (n = 1), stroke after 3 and 48 months, respectively (n = 2), myocardial infarction after 2 and 4 years, respectively (n = 2), hepatic metastasis at 4 years (n = 1), and death of unknown cause at 5 years (n = 1). The probability of survival at 4 years was 78.1% ± 8.6% (Table VI).

Table V. Arterial revascularization procedures performed in 64 patients (multiple reconstructions in 8 patients)

	No.	*%*
Bypass originating at ascending aorta (sternotomy)	5	7
Stenting of common carotid artery (n = 13) or innominate artery (n = 1)	14	21
PTFE carotid bypass	13	19
Carotid vein graft	6	9
Subclavian-carotid bypass (2 vein, 5 PTFE)	7	10
PTFE intercarotid crossover bypass	4	6
Carotid-carotid transposition	2	3
Common carotid endarterectomy	2	3
PTFE carotid-subclavian bypass	4	6
Carotid-axillary artery bypass (2 vein, 2 PTFE)	4	6
Carotid-humeral artery bypass (3 vein, 1 PTFE)	4	6
Innominate-right axillary artery bypass	1	1
Subclavian-humeral artery venous bypass	1	1
Femoral-subclavian-carotid sequential bypass	1	1

PTFE, Polytetrafluoroethylene.

In addition to the two patients with cerebral hemorrhage postoperatively, four patients also had a stroke during follow-up, after 2, 3, 9, and 48 months, respectively; two of these patients died, after 3 and 48 months, respectively. Two major strokes occurred at two different centers during a procedure to restore patency of a left carotid-subclavian bypass graft, after 2 and 48 months, respectively; in both patients an embolism in the left carotid artery was responsible for massive right-sided hemiplegia. One patient had a stroke 3 months postoperatively, after occlusion of an intercarotid crossover bypass graft; respiratory complications led to the death of this patient at 4 months. Nine months after surgery another patient developed right-sided hemiplegia, which regressed over 2 hours; this patient had undergone arterial reconstruction of the right common carotid artery. The probability of freedom from stroke was 85% ± 8.8% at 4 years (Table VII).

During follow-up, after 18 months one patient developed septic complication of a PTFE carotid bypass graft, which required replacement with a vein graft. Six months later a tight stenosis was observed on the distal anastomosis of the vein graft to the internal carotid artery, but no additional surgery was performed.

Four bypass occlusions occurred during follow-up: three in carotid-subclavian bypass grafts after 2, 36, and 48 months, respectively, and one in an intercarotid crossover bypass graft after 3 months. These occlusions were responsible for stroke in three patients and digital ischemia in one patient.

Three stenoses occurred on the revascularized arteries. An asymptomatic proximal anastomotic stenosis occurred after 18 months in a left carotid vein graft; this was managed with repeat surgery, with a PTFE crossover bypass between the right subclavian artery and the left common carotid artery. In another patient recurrent stenosis, 80% asymptomatic, occurred after 18 months in a carotid stent, and was treated with repeat angioplasty. In a third patient, who had undergone carotid-axillary artery bypass, asymp-

Table VI. Life-table survival rates after arterial reconstruction to treat radiation-induced supra-aortic trunk (Kaplan-Meier method)

Interval (mo)	*No. at risk*	*No. lost to follow-up*	*No. withdrawn due to duration*	*No. of deaths*	*Cumulative patency (%)*	*Standard error (%)*
0-1	64	0	0	1	100	0
1-3	63	0	3	1	98.44	1.55
3-6	59	0	2	0	96.84	2.24
6-12	57	1	3	4	96.84	2.28
12-18	49	1	5	1	89.79	4.10
18-24	42	1	1	1	87.84	4.73
24-36	39	2	12	0	85.70	5.19
36-48	25	0	5	2	85.70	6.48
48-60	18	0	9	1	78.08	8.62
60-72	8	0	2	0	72.30	13.45
72-84	6	0	2	0	72.30	15.53
84-96	4	0	1	0	72.30	19.03
96-108	3	0	2	0	72.30	21.97

Table VII. Life-table analysis for freedom from stroke (Kaplan-Meier method)

Interval (mo)	*No. at risk*	*No. lost to follow-up*	*No. withdrawn due to duration*	*No. of strokes*	*Cumulative patency (%)*	*Standard error (%)*
0-1	64	0	0	3	100	0
1-3	61	0	3	1	95.28	2.65
3-6	57	0	2	1	93.66	3.12
6-12	54	1	3	1	91.99	3.54
12-18	45	1	5	0	90.15	4.22
18-24	38	1	1	0	90.15	4.59
24-36	35	2	12	0	90.15	4.78
36-48	21	0	5	1	90.15	6.17
48-60	14	0	9	0	85.00	8.80
60-72	4	0	2	0	85.00	16.46

tomatic proximal anastomotic stenosis developed after 3 years; no additional procedure was performed.

The other arterial revascularizations remained patent during follow-up, and no duplex scans obtained for control purposes revealed any additional stenoses or recurrent stenoses. At 4 years the primary patency rate was 79.3% ± 8.5% (Table VIII), and the secondary patency rate, after any necessary correction of anastomotic stenoses or recurrent stenoses, was 87.9% ± 7.2% (Table IX). We compared the early and late results between surgical and endovascular techniques used to treat lesions of the common carotid arteries. In this series 30 patients underwent carotid bypass, with mean follow-up of 42 months, and 13 patients underwent carotid angioplasty with stent placement, with mean follow-up of 18 months. Among the 30 patients who underwent carotid bypass, 5 patients had a stroke, 1 patient had a septic complication, and 1 patient had an anastomotic stenosis. Among the 13 patients who underwent carotid angioplasty with stent placement, 1 patient had recurrent stenosis; there were no strokes. Endovascular techniques have been used more recently than surgical techniques. It seems that complications were more frequent after surgical treatment, but the difference was not statistically significant ($P = .4$). We also compared the early and late results between saphenous vein bypass grafts and prosthetic bypass grafts for carotid and subclavian arteries. In this series 30 patients received a prosthetic bypass graft and 15 patients received a saphenous vein bypass graft. Among the 30 patients with a prosthetic bypass graft, 6 patients had a stroke, 4 patients had graft occlusions, and 1 patient had a graft infection. Among the 15 patients with a saphenous bypass graft there were no strokes, occlusions, or infections of the bypass graft. Complications were more frequent with prosthetic bypass grafts compared with saphenous vein bypass grafts; the difference was statistically significant ($P = .007$).

DISCUSSION

Radiation-induced arterial lesions of the supra-aortic trunk are infrequent but not exceptional. Their incidence is no doubt underestimated, because they are often asymptomatic[1,4,5,11,24] and the interval between irradiation and the appearance of significant lesions can be quite long.[32]

Note should be made of the considerable heterogeneity of the clinical pictures in our series. The terrain, the clinical course, and the prognosis differ greatly, depending on the location of the arterial lesion. Two main patient groups can be defined: patients who received radiotherapy for breast cancer (30% in our series), in whom lesions of the subclavian artery tend to develop, and patients who received

Table VIII. Life-table primary patency rates after arterial reconstruction to treat radiation-induced supra-aortic trunk disease

Interval (mo)	*No. at risk*	*No. lost to follow-up*	*No. withdrawn due to duration*	*No. of deaths*	*No. failed*	*No. of stenoses*	*Cumulative patency (%)*	*Standard error (%)*
0-1	64	0	0	1	1	0	100.00	0
1-3	63	0	3	1	2	0	98.43	1.56
3-6	59	0	2	0	0	0	95.20	2.72
6-12	57	1	3	4	0	0	95.20	2.76
12-18	49	1	5	1	0	2	95.20	2.98
18-24	42	1	1	1	0	1	91.01	4.21
24-36	39	2	12	0	1	1	88.77	4.76
36-48	25	0	5	2	1	0	83.22	6.82
48-60	18	0	9	1	0	0	79.35	8.50
60-72	8	0	2	0	0	0	79.35	12.75
72-84	6	0	2	0	0	0	79.35	14.72
84-96	4	0	1	0	0	0	79.35	18.03
96-108	3	0	2	0	0	0	79.35	20.82

Table IX. Life-table secondary patency rates after arterial reconstruction to treat radiation-induced supra-aortic trunk disease

Interval (mo)	*No. at risk*	*No. lost to follow-up*	*No. withdrawn due to duration*	*No. of deaths*	*No. failed*	*Cumulative patency (%)*	*Standard error (%)*
0-1	64	0	0	1	1	100.00	0
1-3	63	0	3	1	2	98.43	1.56
3-6	59	0	2	0	0	95.20	2.72
6-12	57	1	3	4	0	95.20	2.76
12-18	49	1	5	1	0	95.20	2.98
18-24	42	1	1	1	0	95.20	3.22
24-36	39	2	12	0	1	95.20	3.34
36-48	25	0	5	2	1	92.22	5.14
48-60	18	0	9	1	0	87.93	7.20
60-72	8	0	2	0	0	87.93	10.80
72-84	6	0	2	0	0	87.93	12.47
84-96	4	0	1	0	0	87.93	15.27
96-108	3	0	2	0	0	87.93	17.64

radiotherapy for head and neck malignancy (50% in our series), who tend to have lesions of the common carotid artery. Eighty percent of the patients in our study had symptomatic disease.

From a surgical standpoint, radiation-induced arterial disease is generally considered to have a poor prognosis; dissection is more difficult, the lesions tend to be more extensive, and there is higher risk for infection and postoperative lymphorrea.[30,33] Although this is true for aortoiliac lesions,[34] the situation is different for carotid lesions. Both the short-term and long-term results of carotid surgery after cervical radiotherapy are comparable to those of such surgery in the absence of radiotherapy.[25-28] As concerns the supra-aortic trunk, all of the procedures usually proposed for treatment of atheromatous supra-aortic trunk lesions proved possible in our patients with radiation-induced arterial disease. Fourteen different procedures were performed in our series (Table V), including direct surgery with sternotomy (n = 5), venous or prosthetic bypass (anatomic or extra-anatomic; n = 45), and angioplasty with stent placement (n = 14). Caution is essential when deciding on the surgical indications in patients with a history of cancer and radiotherapy (Fig 3). Thus direct surgery with sternotomy, which is one of the treatments of choice for supra-aortic trunk lesions,[35] was performed in only 5 patients (8%) in our series. Twenty-three patients (36%) had multiple supra-aortic trunk lesions. Fifteen of these 23 patients underwent vascular reconstruction of only one arterial trunk, and only 8 patients underwent reconstruction of multiple supra-aortic trunks.

Short lesions are usually managed with an endovascular procedure with stent placement.[11,36-38] However, literature series concerning endovascular procedures for radiation-induced arterial lesions are limited, and the long-term results are not known, in particular as concerns the rate of recurrent stenosis.[36-38] Thirteen patients in this series underwent stent placement in the common carotid artery, and another patient received a stent in the innominate artery. One patient developed restenosis of a common carotid artery at 18 months after stent placement. We have compared the early and late results between surgical and endovascular treatment. Endovascular techniques have been used more recently than surgical techniques. In our series, complications were more frequent after surgical tech-

Fig 3. "Hostile" neck after carcinologic surgery and radiotherapy to treat cancer of the larynx. Note greater pectoral muscle flap, skin retraction, and permanent tracheostomy.

niques, but the difference was not statistically significant. None of the patients in our series required angioplasty of the subclavian artery. This seems unusual, but all patients in our series, who had lesions of the subclavian artery, had symptoms. In this context, we think that radiation-induced lesions of the subclavian artery are generally extensive, and endovascular therapy is used to treat short lesions.

For patients with extensive radiation-induced arterial disease, most authors recommend a bypass procedure. For some authors the saphenous vein is preferred, because of the risk for infection,[11,33,39] but this is not always technically possible. The saphenous vein may be not adequate as a result of dense sclerotic tissue that ultimately may compress the conduit. In addition, particularly in the case of carotid-subclavian bypass, the literature supports use of prosthetic material over saphenous vein.[40] In our experience, we most often used prosthetic grafts. We compared the early and late results between prosthetic (30 procedures) and saphenous vein (15 procedures) bypass grafts. In our series complications were more frequent with prosthetic grafts than with saphenous vein bypass grafts ($P = .007$). These results must be interpreted with caution, because the study was retrospective and the population was heterogeneous, with both carotid and subclavian lesions.

Several authors have recommended anastomosis to healthy arteries, avoiding irradiated territories when possible.[11,29,41] Four patients in our series had carotid-carotid crossover bypasses. In two of these occlusion of the graft developed, postoperatively and after 3 months, respectively; both patients had a major stroke, and ultimately died. It is difficult to determine the exact cause of these two early failures, but the extent of the radiation-induced carotid trunk lesions may have been underestimated. We think that carotid-carotid crossover bypass is a less desirable reconstruction in this context, because radiation-induced lesions are often bilateral and both common carotid arteries are affected. Three carotid-subclavian bypass grafts also became occluded, after 2, 36, and 48 months, respectively. These failures can also probably be explained by underestimation of the extent of the radiation-induced axillo-subclavian lesions.[39] Finally, mention should be made of the risk for carotid embolism during thrombectomy of carotid-subclavian bypasses; in two patients in our series massive hemiplegia developed after this type of procedure. This severe complication can be prevented by clamping the carotid artery during thrombectomy of the carotid-subclavian bypass.

CONCLUSION

In light of the context, the results of arterial revascularization for radiation-induced arterial lesions of the supra-aortic trunk are globally satisfactory. In our experience, complications were less frequent with saphenous vein bypass grafts than with prosthetic grafts. Short lesions can be managed with endovascular angioplasty, although the long-term results of this procedure have yet to be established.

Because of the difficulties that can be encountered with these complex lesions (Fig 3), prudence is essential when

deciding on the indications for surgery, after having made sure that the cancer is truly in remission.

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